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THE BIRTH AND GROWTH OF WORLDS

A LECTURE

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A. H. GREEN
M.A., F.R.S.

Claughton Higher Grade Schools

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WORLDS.

A Lecture.

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THE

BIRTH AND GROWTH OF WORLDS.

"Worlds on worlds are rolling ever
From creation to decay,
Like the bubbles on a river,
Sparkling, bursting, borne away."

SHELLEY (*Hellas*).

WHAT a revelation is here for those who listen for the first time to the sublime conception which these words set forth! To each of us individually his own life seems a long span; but the shortness of human life, and the fleeting nature of all connected with it, have been from time immemorial a hackneyed theme with moralists. Like the yearly crops of leaves, we read as far back as

Homer, so are the generations of men; the one pass away as quickly as the other.

But though this is a truth which forces itself early on the notice of mankind, it is quite otherwise with questions about the duration of the world on which we live. The thing which, perhaps more than anything else, makes human life seem short and transitory, is the contrast it presents to the unchanging aspect of much that we see around us. Men come and go, cities are reared and decay, whole nations pass away and their place knows them no more; but the everlasting mountains stand looking upon all these revolutions, themselves, it seems, unchanged; the sea rolls as it rolled when the first man set eyes upon it; the sun gives light by day, and the moon and the stars by night, without, as far as we can see, any weakening of their energy. Nature and her framework are not,

we feel, to be spoken of in the same words as our frail and fleeting existence here. To many people the creation and destruction of the world they inhabit are the Alpha and Omega of their thoughts; the one so far back in the dim past, the other so far ahead in the unknown future, that anything that went before the one, or anything that is likely to follow after the other, is outside the compass of their cogitations; and the lapse of time between these two events seems, when measured by human standards, so enormous, that it furnishes room and to spare for all their meditations; they do not ask or need a wider field. The lifetime of their world is enough for them; and surely, they say, it is long enough.

But how different is the wider view which poetic insight opens to us. Not tying us down to one world, but marshalling before

us a procession in which world follows upon world in long-drawn-out perspective, each treading close on the footsteps of each, like bubbles chasing one another over the surface of a foaming river. And in place of our being permitted to rest in the idea that the lifetime of a single world is so vast that our thoughts can scarcely spread themselves beyond it, we are taught to realize, that, when placed in the illimitable time-vista which now lies open before us, the duration of any one of these countless worlds seems the mere momentary existence of a bubble, which flashes into sight and is gone the next instant.

A new view I think you will all admit, a view fascinating in its majesty and splendour many of you will probably allow; but a very large number of you will, I suspect, qualify your acquiescence with some such short sentence as, "A poet's dream."

I accept the statement. It *is* the dream of one who was a poet; but I ask you to think for a moment what the words mean. What makes a poet? Is it a command of majestic and sonorous language, an ear and an eye quick to catch anything that is musical and everything that is lovely in men and nature, a deep sympathy with his fellow-men, an unwearying play of fancy? It is all these, and many other gifts besides. But there is one thing that more than all is essential, and that more than all marks off the poet from the human crowd, and that is, that in his noblest and most daring flights he has been able to approach somewhat nearer than common mortals to that ineffable source of light from whence all knowledge comes. Hence it arises that he is above the average level of the men of his day, sees things which are hidden even from the wise and prudent

among them, and which will not be recognized as truths till after he is gone. And so it comes about that much which he sings is by his contemporaries set down as wild dream or exuberant fancy; but the generations that follow find it to be sober truth.

The poet's inspiration does not very often concern itself with the concrete objects of sense. "Knowledge and truth and virtue are his theme"; he busies himself more with the hidden mysteries of the inner life of man. But every now and then there rises before him the vision of some great physical truth hitherto unapprehended, or only dimly guessed at by science; this he bodies forth, it may be in somewhat obscure poetic diction. Little heed is paid to what he says; it may be that he himself scarcely realizes the full meaning of his own words. They stand like the response of an oracle, which the faithless laugh

to scorn, but for the accomplishment of which the faithful are content to wait. And in the fullness of time the accomplishment comes, when the slow and painstaking labours of the scientific investigator demonstrate to the world at large what was to the poet a flash of inspiration. It was to a poet that a truth in botany, which may be said to give a unity to that science, was revealed. It was a poet who foresaw all the triumphs which steam has realized, and some which it has not yet compassed. These by way of illustration; time will not suffice for a fuller list of instances.

Now are Shelley's lines, which I quoted at the beginning of my lecture, in any way a case in point? Has Science confirmed his daring utterance?

As yet Science can be scarcely said to have done as much as this, but it has gone a long way towards it. It has shown not only that

there is nothing improbable or extravagant in Shelley's conception, but that the balance of probability in its favour is very large indeed.

The study of an earth's infancy has just that fascination about it which attends all attempts to get at the beginning of things, and speculations on the subject have been rife ever since men began to think.

Burnet, whose work we shall shortly notice in detail, gives expression to this feeling in these words:—"There is a peculiar pleasure to see things in their origin, and by what degrees and successive changes they rose into that order and state we see them in afterwards when completed. . . . To view the Earth and this sublunary world, as it is now complete, distinguished into the several orders of bodies of which it consists, every one perfect and admirable of its kind; this is truly delightful, and a very good entertainment of

the mind. But to see all these in their first seeds, as I may say; to take in pieces this frame of nature and melt it down into its first principles, and then to observe how the Divine Wisdom wrought all these things out of confusion into order, and out of simplicity into that beautiful composition we now see them in; this, methinks, is another kind of Joy, which pierceth the mind more deep, and is more satisfactory." (*The Sacred Theory of the Earth*, seventh edition, vol. i. p. 66.)

It would be of no use to attempt even the barest summary of these speculations, but it so happens the latter part of the seventeenth century produced a large crop of cosmogony-mongers in England, and as their gropings after truth were about the last of the pre-scientific lucubrations on the subject, it will be interesting to give them a passing glance.

A very prominent member of the group,

and one who may be looked upon as typical, is one Thomas Burnet, D.D., a learned divine, who published a book entitled "*The Sacred Theory of the Earth*, containing an Account of the Original Creation, and of all the General Changes which it hath undergone, or is to undergo, till the Consummation of all things. The two first books concerning the Deluge and Paradise; the two last concerning the General Conflagration and the New Heavens and the New Earth."[1]

Burnet in his introductory syllabus concludes, "And this seems to be all that is requisite upon the subject." I think we must agree with him, for I can hardly fancy that any reasonable mortal would ask for more.

It is instructive to notice how Burnet was

[1] This is the title of the seventh edition, published in 1759. The date of the first edition is 1684. The references here are to the seventh edition.

led to the speculations which are expounded in the book with the above startling title. To have hinted that anything like scepticism had found a place in his mind would have given a sad shock to a man of such rigid orthodoxy; but I think it is clear that he did realize that it was not easy to explain how the Deluge and its attendant phenomena were brought about. He had far too much honesty and moral courage to shirk the difficulty when it presented itself, and he seems to have communed with himself somewhat in this way. The account of the Deluge is found in the Bible, and therefore must be true; still it is not on the face of it a very probable story, and it is hard to get people to believe it. I shall be doing good service to the cause of religion if I can show that the development of the earth has been such that a Deluge must necessarily have occurred at a certain period in its history.

And he is very candid: he rejects several explanations as unlikely or contradictory to the Biblical story, and will have nothing to do with such a compromise as that the Deluge was only local.

He first calculates that the quantity of water necessary to submerge the earth to the top of the highest mountain would equal at least eight of the present oceans. "These eight oceans," he says, "lay heavy on my thoughts, and I cast about every way to find an expedient, or to find some way whereby the same effect might be brought to pass with less water, and in such a manner that the water might be afterwards conveniently discharged." The way out of the difficulty which he adopts is briefly this.

The earth sprang from chaos, which contained, mingled without any order, the following elements—earth, the heaviest; lean, earthy

liquids, such as water; fat, oily and light liquids; and air.

When the whole began to settle into order these naturally arranged themselves, the heaviest in the middle, thus.

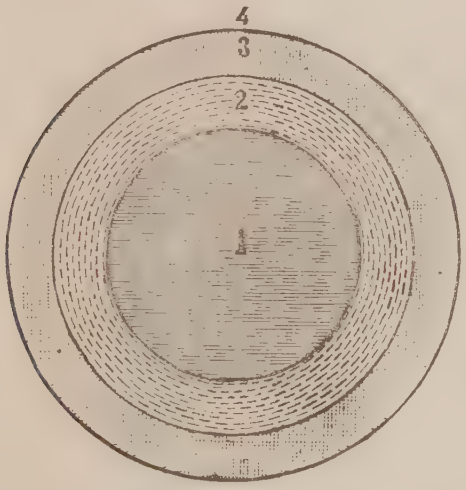

FIG. 1.

1. Earth. 2. Water. 3. Oily liquid with entangled earthy particles, forming, as it dried and hardened, a crust. 4. Air.

But we can readily imagine that the separation would be incomplete, and so in

the air there were floating about small earthy particles, which, settling slowly down, were entangled on the oily shell, and so formed above the water a smooth, level crust of slimy, fat, soft earth. This gradually dried and hardened, and formed the surface of the globe; water all inside.

The position of the earth with respect to the sun was such that there was summer all the year round, and in the course of some hundred years the external earthy shell became "dried immoderately, and chapped in sundry places" by the uninterrupted baking heat of the sun. The heat also penetrating to the water inside, vapourized some of it. So the shell became more and more weakened, till at last it was unable to resist the pressure of the vapour beneath; then it crushed in, and the shattered fragments sank into the watery abyss below. And so you get the Deluge.

Poor stuff this, you say, and not worth raking out of the deserved forgetfulness into which it has all but sunk.

Now had Burnet been a fool, talking after the manner of fools, his childishness would not have been worth noticing. But he was no fool. There are several very remarkable passages in his book, which show that he could use his eyes and observe accurately, and also that, when he was not biased by preconceived notions, he could draw just conclusions from his observations. Take for instance this extract—"For 'tis certain that the Mountains and higher parts of the Earth grow lesser and lesser from age to age." He then mentions several causes that tend to bring about this result, and goes on—"But there are also other causes that consume them insensibly and make them sink by degrees; and these are chiefly the Wind, Rains, and Storms, and

the Heat of the Sun without; and within the soaking of Water and Springs, with Streams and Currents in their Veins and Crannies. . . . So the higher parts of the earth being continually spending, and the lower part continually gaining, they must of necessity at length come to an Equality" (p. 47). The doctrine here enunciated is now an essential article in the creed of every geologist. But nearly a century elapsed before the penetrating genius of Hutton established on the sure basis of observation this fundamental canon; and nearly half another century passed away before its truth was generally admitted by geologists.

Our author also now and then puts forward speculations on physical questions which show him to have been a man of parts. Then how was it that he could produce nothing better than this childish babble? This is the reason.

He was speculating on questions in natural science, and we know now that the only safe road in such a case is to go to Nature herself, and to go with a mind purged from all foregone conclusions. Burnet went to a book first; he started from the theological dogma that every statement in that Book must be taken as literally true; and his aim was not to discover the truth and stand by the result, whatever that might be, but so to twist and turn facts, if they could be twisted, as to support the statements of that Book; and if facts would not serve his purpose, to supply their place with baseless guess-work.

But, I pray you, don't misunderstand me; I beg you to believe me when I say that I am not capable of speaking of that Book in any other words than those of the deepest love and reverence. But for all that, I don't go to it for my science.

What I have said of Burnet applies to several of his contemporaries—Woodward, Whiston, Whitehurst, even Ray, all men of mark and of whom it would ill become me to speak lightly. But they all got hopelessly wrong, and for just the same reason as Burnet.

One or two short samples of the wild guess-work, which passed with these men for scientific speculation, must suffice. In Woodward's *Essay towards a Natural History of the Earth* (1695), the author promises well to begin with. He lays down that "The world is at length convinced that *Observations* are the only *sure grounds* whereon to build a lasting and substantial *philosophy;*" and goes on thus—"For which reason I shall in the work before me give myself up to be guided wholly by *Matters of Fact.*" And in some measure the man kept his word. He did observe, and to some purpose. His collection

is still preserved at Cambridge, and it shows that he must have worked on British rocks with great industry and considerably acumen, and that he went a long way towards determining the order of their super-position. But what are we to say to this? "Of all the various leaves and fruits which I have seen lodged in stone, I have observed none further advanced towards maturity than they are wont to be at the latter end of the spring season, when, according to the Mosaic relation, the waters of the Deluge came forth, and put a stop to the growth of both animals and plants." No "matter of fact" this, assuredly; but what ought to be, and therefore what was. Or again this, which presumably is one of his "matters of fact," when he states that the exterior stratum of the antediluvian earth consisted of terrestrial matter proper for the nourishment of plants, not entangled with an

intermixture of mere mineral matter unfit for vegetation, and so scarcely any cultivation was needed. Man in a state of innocence did not abuse the leisure thus vouchsafed him; but fallen man took advantage of it to indulge his vicious propensities. The Deluge, by mixing the terrestrial nutritious earth with much mineral matter, made cultivation necessary; and so man, having to work more, had less time to sin. He admits that this has not done all that could be wished to diminish wickedness; but believes that things would have been much worse if the check had not been imposed.

Whiston again was mathematician enough to appreciate the Principia, and the success of Newton and Halley in determining the orbit and period of the great comet of 1680. So he made this comet do duty in solving the to him one great problem of accounting for the

Deluge. His guesses are as wild as the generality of the guesses of the day on this subject; but it is amusing to note the gravity and *naïveté* with which he dilates on the improbability of Woodward's hypothesis. A case, verily, of the pot calling the kettle black; but the pot is very earnest and serious about the blackness of the kettle.

Whitehurst was a man of very much the same type as Woodward. A painstaking and accurate observer, and, where pre-conceived notions did not come in to warp his judgment, a sound reasoner. His account of the geology of Derbyshire is, as far it goes, singularly accurate. He convinced himself on the most logical grounds that some rocks in that county, known as Toadstones, and that the Basalt of the Giant's Causeway, are old lavas—a truth which was disputed for more than a century after his day. But he too got entangled on

the great Deluge problem, and his attempts to solve it are no less lamentable than those I have already noticed.

Another thing that strikes us about these men is the extreme narrowness of their views. They never get outside the compass of this little earth. The boundless universe, with its myriads of worlds and systems of worlds, has no interest for them. They do not even care much for the physical history of that one world as a whole; one incident and one only, the Deluge, need be accounted for; explain how that happened, and everything else was matter of very second-rate importance.

But even while these men were floundering in the quagmires of unscientific guess-work, the time was ripe for better things, and other men were attacking the problem in a more promising spirit.

They owed their superiority over Burnet

and his fellows mainly to two things. First, they had realized that, if you want to know anything about Nature, you must not go to books, however much these books are deserving of respect, but that you must set yourself down face to face with Nature herself and question her; or if you cannot obtain all your facts at first hand, as of course very few men can, you must take them only from the mouth of such men as have questioned Nature, and questioned her in the right spirit, with the single-mindedness which seeks only to reach the truth and not with the intent of bolstering up some preconceived theory.

They based their speculations not on the assertions of the writers of antiquity, nor for the matter of that upon the views of any writers at all, but on the facts learned by diligent reading of the great book of Nature. And when they came to frame hypotheses to

account for these facts, they admitted only so much of conjecture as followed logically from the result of their observations.

Secondly, these men I am speaking of were thoroughly versed in all the most advanced science of their day.

One result of their method was increased breadth of view. The earth, and what has gone on upon it, were not all in all to them. Its history is only a very small item in a grand scheme, which takes in the development of the whole visible universe, and may apply to regions beyond the reach of our vision. There is another striking difference between these men and the dreamers we have hitherto been dealing with. Among the latter each had his own special solution of the problem he was attacking; their speculations agree in being all wild and improbable, but beyond this feature they have nothing in

common. The hypotheses of the men we are now coming to differ in their details, but they are linked together by a great central conception that is common to them all. Since these hypotheses were for the most part arrived at independently, this undesigned coincidence furnishes some presumptive evidence in their favour.

The outcome of observation and reasoning on the part of these men was a scheme of the origin of the universe, known as the Nebular Hypothesis, of which the following are the most prominent features.

The material of which planets, sun, stars, comets, and all the other heavenly bodies consist was at one time in a vastly different state from what it is now. Instead of being made of a great variety of substances, it was everywhere the same, and extremely simple in its nature; and instead of being collected

into a number of separate bodies, it filled all space. We want a name for this substance, and a very good one has been lately suggested by Mr. Crookes, viz. *Protyle*.

From time to time certain centres became established towards which the surrounding protyle was drawn in, and so the great uniform body of protyle became more or less broken up into separate masses.

The same process was repeated within each mass, so that it again was further broken up into smaller masses, and the sub-division might be repeated many times over.

In each of these masses a process of further separation and development went on, and thus out of each suns and their attendant systems of planets were developed.

And the very same process which thus on the large scale collected the protyle into individual bodies, was all along affecting in

a similar way its minute internal structure. Originally everywhere the same, and without differentiation, portions of it combined into what we should now call atoms or molecules, and the first rudiments of chemical elements made their entry into being. The first formed would be extremely simple, such as Hydrogen, or something even simpler still in its molecular structure. By a combination of these first formed elements, new bodies with a more complex structure would arise, and so the differentiation of matter into the forms under which we know it now, would be arrived at.

And this double work of concentration and individualization did not begin everywhere through the universe at the same time. It started at some places earlier than at others, and there can be no reason for thinking that it has now ceased. So we should expect

matter still to exist in every stage of development, and it is only reasonable to think that the work has been going on during a past longer than we can conceive, is now going on, and will keep going on during a future to which we can place no limit.

Vague foreshadowings of this conception suggested themselves to various thinkers from time to time. It was first put into a definite and tangible shape by the philosopher Kant in 1755. Kant is generally known as the author of certain metaphysical writings, so abstruse in their character that they are looked upon by the many as unintelligible; but he was also a mathematician, a physicist, and generally well abreast of the science of his day.

Somewhat later Laplace struck out independently a similar hypothesis, which he afterwards developed more fully when he became ac-

quainted with the observations of Sir W. Herschel on nebulæ.[1]

The spirit in which Laplace looked upon his hypothesis is altogether refreshing. He says it is an hypothesis, "que je présente avec la défiance que doit inspirer tout ce qui n'est point un résultat de l'observation ou du calcul." What a contrast to the rash presumption of Burnet and his school, who never seem to have had a tittle of misgiving as to the full and perfect sufficiency of their dreamy explanations!

Not long ago Mr. Crookes in a magnificent address enlarged our conception of the nature of protyle, and of the way in which all the multifarious substances we now possess may have been elaborated out of it.

[1] The first sketch of this scheme appears in the first edition of the *Système du Monde*, published in 1796: it is expanded in the edition of 1824.

The grandeur and comprehensiveness of this scheme contrast very forcibly with the narrow range of men like Burnet. They never look outside this puny earth, or beyond the short time during which it has existed; and to explain how one or two events, or supposed events, in the earth's history have been brought about is all they aim at in their physical conjectures.

Kant's vision knows no bounds; his speculations spread themselves to the very uttermost realm of space, and range through a boundless past and a boundless future of time. Nor does he by any means limit himself to the physical side of the subject. The grandeur of the scheme is to him a proof of a corresponding grandeur in the power which could elaborate, set going, and maintain so magnificent a piece of machinery. The majesty of Nature is ever suggesting to his mind the still greater majesty

of the Lord and Master who controls her workings. The boundless realms of space, he says, are thronged with world-systems whose number and perfectness are proportioned to the immeasurableness of the Creator.

He is very much impressed by the way in which matter works out its own development. The capability inherent in the nature of things to raise themselves *of themselves* to order and completeness, is to him a most beautiful proof of the presence of God. A higher conception this than Burnet's.

It was mainly with a view of bringing out this contrast that I have ventured to take up your time with a sketch of the vagaries in which theologians and others who were not men of science have indulged in their attempts to trace out the growth of the universe.

For I have not laid before you the crude speculations of Burnet and his fellows in order

to hold up to derision men who, however their minds may have been warped, were earnest and sincere; nor merely because the history of the growth of thought is interesting and instructive. There is another aspect of the question besides the scientific. I need scarcely point out how limited and mechanical must be our conception of the character and aims of a God who worked after the fashion imagined by Burnet. But Kant looks up to a Creator under whose hand space is becoming ever more and more thickly peopled by new worlds and systems of worlds; who is ever extending His empire and giving fresh proofs of His grandeur and wisdom. His work is not limited either by space or time; it is boundless and endless as Himself. And I say to you, as Joshua said to Israel of old, Choose you which God you will serve (Josh. xxiv. 15)—the God of the pseudo-theologian who subordinates facts

to antiquated and narrow dogmas, or the God of the philosopher and man of science, who goes direct to Nature for his knowledge of the material universe. I venture to think that I know what your answer will be, for I have great hopes that I have succeeded in convincing you, that it is sound science that leads us up to the highest and noblest conceptions, even on matters that are often thought to lie outside the domain of physical science.

One of the first questions we naturally ask when this hypothesis is propounded to us is, are there any grounds for believing in the former existence of protyle?

There are *à priori* considerations which make it not improbable.

One main part of the work of chemistry has been to show, that bodies for a long time looked upon as simple are really compound, *i. e.* made up of two or more different substances.

Take the common instance of Water, called for centuries an element or simple substance. Heat it sufficiently, and it becomes a vapour or gas, Steam; heat it still more, and the steam splits up into two gases, totally different from it and one another, Oxygen and Hydrogen. Beyond this chemists have not been able to get; by no means at their disposal have they yet been able to split up these two gases, to get anything out of oxygen but oxygen, or anything out of hydrogen but hydrogen.

But it is not believed by chemists that oxygen and hydrogen are for this reason necessarily simple substances; many of them hold, that if we had more powerful means of separation, say very much higher temperatures, oxygen and perhaps hydrogen too could be resolved into some simpler elements. And some eminent chemists have been of opinion, that there are strong grounds for believing that

all the so-called elements are compounds of a few much more simple substances, or are even merely different forms of one ultimate substance. It is just such a simple substance that we conceive protyle to have been. In its undifferentiated state it would possess a great store of potential energy. As combination proceeded this would become active, and might give rise to great heat.

Chemists can give grounds for their belief, which it would be impossible to go into here. But there are reasons derived from the study of certain heavenly bodies, known as nebulæ, which lend support to the hypothesis we are considering and which admit of easier explanation. We will first give a sketch of the views which till lately were very generally held about these bodies, and of the form in which the nebular hypothesis used to be enunciated.

These nebulæ appear to the naked eye, or

when seen in a telescope of low power, like masses of cloud or mist, shining with a dim hazy light. Some of them when seen through powerful telescopes were found to be clusters of stars; but there are others which no telescope was able to resolve into stars. The true nature of these was doubtful till the spectroscope made them write their own story, and it is known now that many of them are composed, in part at least, of gas at a high temperature; some probably are wholly gaseous.

Their spectrum is very simple, and indicates that only a few of the simplest of the chemical elements are present in them. Here then it was conjectured that we may have protyle in which the work of differentiation into elements has advanced only a little way.

The stars were next questioned. They are largely liquid or solid. Their spectra are on the whole more complex than those of the

nebulæ, but they exhibit various degrees of complexity.

Attempts were made to parcel out the stars in groups, corresponding to different stages in their development. Some stars shine with a white light; their spectra are simple, but they indicate the presence of more elements than have been generally recognized in nebulæ, and such stars might be looked upon as being in a rather more advanced stage than nebulæ. Then again there are yellow stars, of which our sun is one, with spectra more complicated than those of the white stars, and therefore perhaps in a stage of development still more advanced than these. There are stars of a third class, often red in colour, in which it was thought that differentiation had been carried further than in yellow stars.

It looked as if we might pass from red to yellow stars, thence to white stars, and beyond

these to nebulæ, and find increasing simplicity of structure at each step.

These views have not entirely stood the test of more careful investigation. But we may yet safely assert, as a matter of fact, that there are in the celestial space immense bodies, consisting largely of gas at a high temperature.

Can we conceive any reasonable way in which one of these could be transformed into such a planetary system as our own?

We suppose the heated mass to be rotating about an axis; some of the nebulæ seem to have such a rotation. Various suggestions have been made to explain how the spin was brought about; but they hardly admit of being put in a popular form. One possible source of the heat has been already hinted at.

The hot mass will cool, and so contract. Contraction will make it rotate faster. You

are all familiar with the domestic experiment of twirling a mop. At first no result follows, but as you spin it faster and faster, the water at last begins to fly off. In the same way the nebulous ball will at last spin at such a rate that it can no longer hold together, and a ring will be thrown off round its equator. This ring will at first spin round in the same direction as the ball it has left. But the ring cannot hold together. It breaks up and collects into a ball. This ball revolves in the same direction as the nebula of which it originally formed a part, and at the same time rotates in the same direction round an axis parallel to the axis of rotation of the nebula.

Further contraction will cause another ring to be thrown off, which will likewise collect into a ball.

So in the end we shall have a number of

balls all revolving in the same plane about a common centre, and rotating all in the same direction about axes perpendicular to that plane. And in the centre a large mass still in a gaseous and heated state.

The balls, being small, will cool and condense into planets; the central mass, being large, will retain its heat much longer and will form a sun.

It may happen that some of the balls will as they contract throw off rings which will collect into balls, and so we shall get moons revolving about some of the planets.

This is very nearly the constitution of our solar system. With one, or perhaps a few, singular exceptions among the outermost bodies, the planets and moons all move round the sun in the same direction and in planes inclined to one another at small angles, and all rotate about axes nearly perpendicular to

their common plane of revolution in the same direction as they revolve.

The probability that such an arrangement could have been brought about by chance is so infinitesimally small, that we are driven to the belief that it is a necessary consequence of the way in which the solar system came into existence. The facts point to some common origin for all the members of the system, and to some common scheme according to which the system has grown into its present shape; assuming, of course, that it reached its present state by some process of natural evolution, an assumption to which analogy leads. The nebular hypothesis furnishes us with such a scheme and such an origin.

I now throw on the screen an experiment which will exhibit a ball of oil floating in a mixture of spirit and water of the same density

as itself, and rotating about an axis. As the rate of spin increases, a ring is thrown off which collects into a ball that revolves about the original central mass. It is useful as an illustration, but it must be carefully borne in mind that the balls are here held together by surface tension; while in the case of a rotating nebula, it is the mutual attraction of the particles that determines their aggregation.

The nebular hypothesis left the hands of Kant and Laplace in the somewhat vague form in which I have presented it to you. The labours of other mathematicians have introduced into it greater precision of detail, and in the course of the last few years Professor George Darwin has engrafted upon it the doctrine of Tidal Evolution. The way in which he has applied his methods to the case of the earth and the moon has been so recently expounded by Sir Robert Ball,

that I need do no more than give it a passing recognition.[1]

The ingenuity of man still plays around the fascinating question on which we are engaged; and one more speculation must be noticed if I am to bring my summary up to date.

You all know how largely the spectroscope has added to our knowledge facts about the heavenly bodies, which before its application we should have been almost justified in saying must remain for ever beyond our ken. It is very largely by spectroscopic evidence that Mr. Lockyer has been led to the views I must now speak of.

We know that the celestial spaces are not the empty void they were once thought to be. Were our vision good enough, we should see them thick with crowds of stones and dust, careering wildly in many directions, and

[1] *Time and Tide*, by Sir R. Ball. S. P. C. K.

dragged out of their path on to the larger bodies whenever they come into the neighbourhood of these; so numerous that it has been estimated, that as much as a hundred tons weight of them are encountered by the earth every day, and fall upon its surface. The larger are known as meteorites. But it is with the very small that we have first to do. When the resistance of the air suddenly checks their rapid flight, heat enough is generated to turn them into glowing vapour, and we have "shooting stars."

Such may be seen singly or in scant numbers on any clear moonless night; but all of you have heard of, and many of you may have seen, one of those wonderful displays, in which they come in such crowds, that all night through the heaven is one blaze of countless meteors. One of these very great displays was witnessed in November 1833, and on

looking back, it was found that there were records of many similar star-showers in the past at about the same time of the year. It was found that everything could be completely accounted for on the supposition that an immense crowd of very small bodies was revolving round the sun in a very elongated orbit, with a period of $33\frac{1}{4}$ years. The orbit crossed that of the earth at a point which was passed by us about the middle of November, and it so happened that the earth and the thickest part of the crowd just met at the intersection of the two orbits. It was predicted that the shower would happen again in 1866, and the forecast came exactly true. Then Schiaparelli noticed that the orbit of the meteorites coincided exactly with that of a comet known as Tempel's comet, the meteors, which are known as the Leonids, following in the track of the comet.

Another great meteoric show takes place in August. Here again the orbit of the meteorites is the same as that of Tuttle's comet. These meteors are styled the Perseids.

Meteors and comets are apparently closely akin.

A third comet, Biela's, showed the nature of the relationship. It had a period of six years and eight months, and its return had been several times observed, well up to time, between 1772 and 1845. In the latter year it split into two, and both parts reappeared in 1852. Since then it has been never seen again, but a swarm of meteorites travels along its orbit, and produces a star-shower towards the end of November. There could scarcely be a doubt that the comet broke up, and that the Andromedes, as these meteors are called, are its disintegrated fragments.

All these facts seem to point to the conclu-

sion, that some comets at least are swarms of stones revolving in definite orbits round the sun; as their velocity increases towards perihelion, the stones will bang against one another more and more violently and frequently, till they are rendered incandescent and partly volatilized. But in a loose aggregate of this kind the tide-producing action of the sun will tend to separate the individual members, till they become widely dispersed along the whole, or a large part, of the orbit; so that what had been first noticeable as a comet, later on is even more conspicuous as a meteoric shower.

To test the hypothesis, Mr. Lockyer has examined the spectra given by fragments of fallen meteoric stones under different conditions of temperature and pressure. He finds points enough of resemblance between these spectra and the spectra of comets to give support to the "shower-of-stones theory."

Mr. Lockyer has further made a comparison between the spectra obtained from these meteorites and the spectra of nebulæ. Here his results are quite compatible with the notion that nebulæ may be swarms of meteorites shooting hither and thither among themselves, and clashing against one another till they are rendered incandescent and more or less vaporized. He believes also that low electrical excitation helps in producing the results observed. He himself would speak more positively on the point perhaps, but as his conclusions are not quite universally accepted, and as he himself allows that his investigations are as yet incomplete, I trust he will excuse the caution of one whose ignorance makes him wary.

Details of his work can hardly be given, but this will supply some notion of his reasoning. When fragments of meteorites inclosed in a vacuum tube, along which an electric discharge

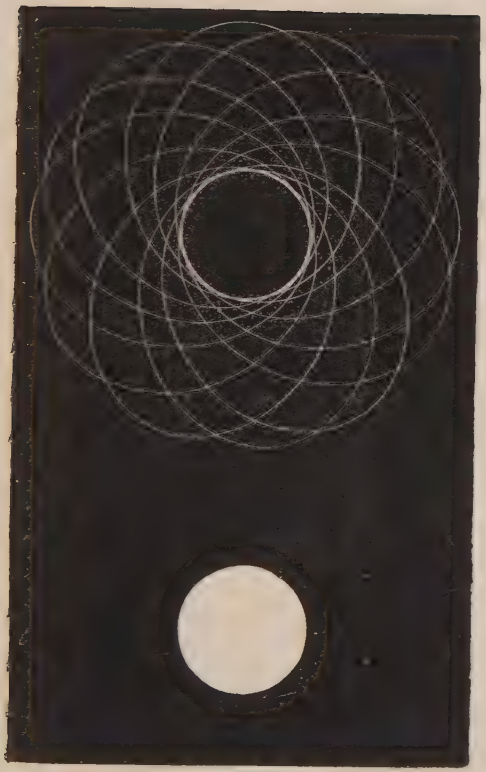

FIG. 2.

is passing, are moderately heated, the spectrum of the glow agrees with that of nebulæ, and of some comets when at a distance from the sun; by raising the temperature we obtain a spectrum of the glow resembling that of some comets when nearer to the sun.

By way of illustration I reproduce in Fig. 2 one of his diagrams. It shows what might happen if we had a number of meteorites revolving in orbits of approximately equal size and ellipticity about their common centre of gravity, the motion being in some cases direct and in others retrograde. It is evident that collisions would be most numerous along the thick white circle, and that here accordingly there would be the maximum of incandescence and illumination. If this went on over a large number of planes instead of one, we should have a glowing sphere, which would show like the circular disc of light below.

Fig. 3.

Mr. Lockyer also discusses the case of those bodies, which are to all appearance stars, but which must be partly gaseous because they give bright lines superposed on a continuous spectrum, and comes to the conclusion that they have a constitution analogous to that he assigns to nebulæ.

He has embodied his results in the curve in Fig. 3.

Starting at the bottom, on the left we have a widely scattered crowd of meteorites. As we ascend the swarm becomes more and more thickly packed; the collisions become more numerous and violent, and increased temperature results. More and more is also vaporized, and when we reach the summit where the temperature is at its maximum, the whole may be reduced to a state of vapour. Descending the right-hand line, the temperature

FIG. 4.

is falling, the vapours condense, and the swarm tends to consolidate.

I think it is just worth calling attention to the ingenious way in which Mr. Lockyer has applied his hypothesis to account for the phenomena of variable stars. He supposes that a variable star is a meteor-swarm revolving in an orbit around another swarm, the relative position of the two being such as is shown in Fig. 4.

Obviously when the revolving swarm is rushing through the other swarm, collisions and therefore brilliancy will enormously increase. When it gets clear, the collisions will be fewer and the light fainter.

Such then are some of the more important hypotheses as to the growth that has gone on, and is still going on, among the celestial bodies. So speculative are they all, that the lapse of centuries seems to bring us no nearer

to certainty. But we may take comfort in the assurance that all our attempts now start from a solid basis of fact, and are controlled by a logic that cannot err. No such dreamy guess-work as passed muster two hundred years ago would be tolerated now.

The following are some of the chief works bearing on the subject of this lecture.

LEIBNITZ—'Protogæa,' 1680.

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